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SIMULATION REQUIREMENTS FOR THE DEVELOPMENT OF ADVANCED MANNED MILITARY AIRCRAFT (U)

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INTRODUCTION

Paralleling the large increase in the performance capability of present airplanes has been the increase in the problems connected with the design and operation of these vehicles. Indications are that the designer of advanced military aircraft will be faced with the present "crop" of problems as well as additional problems as yet unborn. Many methods have been devised to study these problems, but perhaps no single method of analysis has achieved the success and universal acceptance of the flight simulator as a design and research tool. This was made possible by the tremendous advances in development of the analog computer which has been used to solve almost any problem that can be represented by a differential equation.

Some of the most useful simulations have involved the pilot in the control loop. A drawing illustrating a pilot-operated flight simulator is presented in the first slide (1). Illustrated is the flow of information from the computer to the pilot and back to the computer. The pilot is the key link closing the loop.

NASA has had considerable experience with a wide variety of piloted flight simulators, from relatively simple, inexpensive, fixed-chair types to complex and expensive human centrifuges and variable-stability and control airplanes. As indicated in slide 2, these simulators fall logically into two groups by virtue of their operational environment: ground based and airborne. This slide needs no explanation except, perhaps, by example. The fixed-base simulator was

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described in the first slide. The moving visual environment refers to a dome-type simulator or a television-camera sensor with six-degrees-of-motion freedom with appropriate projection on the pilots' screen. The moving-base simulators provide linear acceleration, such as the normal-acceleration chair or the Navy human centrifuge at Johnsville, Pa. Other simulators provide angular acceleration or attitude; an example is the pitch-roll chair. Some simulators provide both motions. The flight vehicles refer to variable-stability airplanes, for example the NASA F-100C airplane. The NASA also has a variable-stability helicopter and a variable-stability VTOL, the X-14. Variable-control-system airplanes have also been tested, as has a variable-control helicopter. The low-dynamic-pressure airplane refers to reaction-control tests with the F-104 and hovering tests with the VTOL aircraft, while the low-lift-drag-ratio landing tests refer to the simulation of the X-15 landing with the F-104. Some of the aircraft design problems that have been studied in varying degrees by NASA are listed in the next slide (3). The ~~major~~ problems studied ~~areas~~ are grouped, more or less arbitrarily, into three major headings: basic airplane design, major system design, and mission analysis.

This backlog of experience has provided considerable information on and insight into the simulator complexity required for a wide variety of aircraft design problems. It is the purpose of this paper, first, to review some of the more recent simulator results, with special emphasis on the airplane design problem areas where comparisons are available with flight. Second, based in part on an extrapolation of these results, ~~the~~ simulator requirements for the design of a low-level attack airplane will be presented.

INTRO

By using simulators and variable-stability airplanes, the stability and, damping requirements for both the longitudinal and the lateral-directional motion modes of airplanes have been studied. Representative results are presented on the next slide (4) showing areas, obtained in flight with a variable-stability airplane, considered by the pilots to have satisfactory, unsatisfactory but permissible for augmentation-out condition, unacceptable, and uncontrollable longitudinal characteristics. This same range of airplane dynamics has been investigated by the same pilots using a fixed-base simulator and a moving-base simulator (the pitch-roll chair). In general, there was little difference in pilot opinion, comparing the results from the simulators and from flight for desirable dynamics. However, as the airplane dynamics became poorer, tending toward the minimum acceptable at high frequency, differences in the pilots' evaluation were noted. The next slide (5) correlates the pilot-opinion results from the piloted simulator tests with the flight results. The correlation of both simulators with flight is near perfect until the region of poor airplane dynamics is reached, where the fixed-base simulator correlation becomes poor but the moving-base simulator correlates to extremely poor dynamics. In fact, dynamics which were unflyable with the fixed-base simulator were controllable with the moving-base simulator and in flight, thus showing the need for motion stimulus for conditions of very poor dynamics. The fixed-base simulator, however, was completely satisfactory for a wide range of airplane dynamics.

The lateral-control requirements for manned airplanes have been determined also (slide 6). This study used the roll-chair piloted simulator as a single-degree-of-freedom motion simulator. Important parameters were found to be roll-control power and roll damping. Satisfactory to unacceptable regions were defined by pilot opinion. These results correlated with flight results, as is shown on the next slide (7). These moving-base data show a somewhat optimistic correlation with the flight results; however, the correlation is considered fair, considering that the moving-base simulator provided only one-degree-of-freedom motion stimulus, whereas the flight provided six degrees of freedom. Tests were also conducted with a fixed-base simulator with the same pilots. These results were similar to the moving-base results except for the sensitive control areas (poor pilot rating) where the fixed base correlated less well.

A flight investigation has also been conducted using a variable-stability airplane to determine the effects of varying amounts of favorable and adverse yaw (slide 8). The investigation indicates favorable agreement throughout the test range, showing the acceptability of the fixed-base simulator for the investigation of the control coupling problem.

In addition to the work on conventional aircraft just described, considerable ground-based simulator work has been completed recently in defining control requirements for V/STOL type aircraft. In addition to these generalized studies, investigations have also been made of the hovering and transition characteristics of several specific V/STOL types using six-degree-of-freedom analog simulation with a moving cockpit providing pitch and roll motion stimulus. Concurrent flight tests of these V/STOL aircraft have permitted a preliminary assessment of the degree of comparison between single-degree-of-freedom simulator results on hovering control requirements and flight-test results. Also, qualitative comparison of the six-degree-of-freedom simulator results with flight results on specific aircraft has provided some indication of the general utility of a moving-cockpit simulator for studying the hovering and transition characteristics of V/STOL type aircraft.

Data obtained during the generalized study of control requirements during hovering are shown in the next slide (9). It should be noted that the important parameters--control power and damping--are the same as those defined previously for lateral control of conventional aircraft. Also shown are the basic control power and damping characteristics measured in flight for several VTOL aircraft. Although the flight data are limited, the single-degree-of-freedom simulator results would indicate that airplanes C and D have satisfactory pitch-control characteristics, while aircraft A and B would be expected to rate unsatisfactory. Similarly, the roll control of airplanes A and C appears satisfactory, while aircraft B is in a definitely unsatisfactory region. Actual flight evaluations of the pitch and roll controllability of these aircraft are correlated with the pilots' opinions in the next slide (10). Generally, the predicted ratings from the moving-base simulator tests are in fairly good agreement with flight; however, they appear, in general, to be optimistic; that is, they tend to underrate the actual control problem. Indications are that secondary factors such as control-system leadband, friction, etc., which were not simulated may account for the differences shown.

Although no quantitative comparisons are available for fixed- or moving-base simulators and flight evaluations of overall hovering and transition characteristics of V/STOL airplanes, it is felt that a brief qualitative resumé of experience to date may be of interest. From the pilots' point of view, an analytical six-degree-of-freedom simulation in conjunction with a moving cockpit which provides two-axis motion in pitch and roll has proven quite valuable for pilots' practice of expected control problems prior to initial flight tests. The simulator experience also permitted the pilot to determine piloting techniques for recovery from unusual flight conditions. However, because the simulation did not include an adequate presentation of the external visual references the pilots would have in flight, the pilots observed no direct correspondence between hovering height control and transition capability in the simulator and in flight. When definite limitations in the simulation have been noted on the piloted flight simulator such as just described, it has been helpful for the pilot in evaluating a new configuration to fly a simulation of an airplane with which he has had recent flight experience. This serves to orient or calibrate the pilot to the limitation of the simulation so that he can evaluate objectively the relative difficulty of the new airplane.

Recent NASA pilots' evaluations of fixed-cockpit simulators, which provide six-degree-of-freedom simulated external visual environment, have indicated that this type of simulator is admirably suited to the V/STOL simulation problem, particularly for accurately evaluating the hovering and transition characteristics of these airplanes. The addition of three-axis angular motion would be desirable, but perhaps not essential, for this problem.

Another design problem in which the simulator has been used is for checking the pilot's presentation. Tests have been made using an airplane, a moving-base simulator, and a fixed-base simulator to compare the pilot's performance while tracking with an inside-out and an outside-in target display. The performance of the pilots was very poor with the outside-in display for both the flight and moving-base simulator, while the performance with the inside-out display was acceptable. These results did not correlate, however, indicating some basic deficiency in the presentation or motion stimulus. With the fixed-base simulator the pilot's performance with either of the displays was comparable, showing the absence of motion-stimulus effects. From these tests, it was concluded that a fixed-base simulator should not be used for the evaluation of tracking displays and that the results from moving-base simulators should be extrapolated to flight with reservation.

The fixed-base simulator has been used extensively during the design of airplane displays. Early in the piloted simulator program of the X-15 airplane a scanning problem was noted by the pilots, which led to a rearrangement of the panel instruments. Current flight tests have shown no new deficiencies not previously corrected during the fixed-base simulator tests.

Thus far we have discussed specific design problem areas that have been investigated on simulators and in flight. To illustrate further the importance of the piloted flight simulator, we shall consider briefly a design program that probably would not have been possible without the piloted flight simulator--the X-15 research airplane. Flight simulators dictated many important design changes to the airplane, but perhaps their most important contribution was to emphasize the need for a complete simulation. The difficulty of the control task during certain parts of the flight envelope showed the need for a moving-base simulation program to investigate the capabilities of the pilot while subjected to the accelerations expected of the airplane. Consequently, a program was conducted utilizing the human centrifuge to impose the expected acceleration on the pilot while piloting the simulated X-15 mission. The mechanization of the centrifuge for this program is shown in the next slide (11). During this simulator program it was determined that even at the highest acceleration expected there was little deterioration in the pilot's performance. Exposure to the expected accelerations gave the pilot confidence in his ability to cope with the physiological and psychological problems of actual flight.

At present, a complete six-degree-of-freedom X-15 simulator, including the control-system hardware, an airplane-like cockpit with all the functional pilot's controls, and with actual electronic components of the stability augmentation system, is being used for flight planning, pilots' practice for flight, and for verification of airplane flight behavior after flight. The pilots have enthusiastically endorsed the use of the fixed-base piloted flight simulator for becoming acquainted with the piloting task before actual flight.

Perhaps the most significant contribution from the X-15 simulator program will be correlation of the data from flight, moving-base simulator, and fixed-base simulator for defining the simulator requirements for the design of future manned military and research airplanes.

Experience from several centrifuge programs has shown that to determine the tolerance limit to acceleration a centrifuge is necessary, but for the investigation of airplane control problems the centrifuge is not satisfactory, nor considered necessary.

From the discussions at this meeting, a requirement has been indicated for several types of manned military airplanes. For this presentation we have chosen to examine briefly the simulator requirements for design of the low-altitude attack airplane.

This airplane is expected to operate over a wide range of speeds and altitudes, from supersonic speed at very low altitude to either subsonic or supersonic cruise at high altitude. Within this envelope the airplane operates over a dynamic-pressure range of about 200 to 2,000 pounds per square foot and encounters many design problem areas new to the attack airplane. Some of these are listed on the next slide (12). Shown also is a sketch of this type of airplane which indicates problems that might be expected.

Previous discussions in this paper have indicated that many of these problem areas can be resolved by using a fixed-base simulator; the one big exception is the piloting problem encountered with the high-performance airplane in turbulent air. Recent tests have shown that both the controllability and pilot fatigue are important in the investigation of control of the airplane under these conditions. A moving-base simulator which duplicates the normal acceleration of the airplane will be required for this problem. [Possible photo of NAA g-seat.] This type of simulator is a relatively inexpensive piece of hardware and could, it appears, justify its cost for the investigation of this one problem. The inclusion of bank angle on this simulator would add realism, but would probably not be required.

In the past, the flight simulator has not been used for preliminary design of the airplane, but for this airplane the piloted flight simulator will be required to assess the problem areas just reviewed.

A fixed-base simulator with three degrees of longitudinal freedom will be useful for performance estimates and for a preliminary assessment of the longitudinal-control problems. In addition, a constant-velocity mechanization with five degrees of freedom would be useful to investigate lateral-directional control problems and roll coupling.

Paralleling the aerodynamic development of the airplane will be the system development. Once the aerodynamic design is frozen and an operational mockup of the control system and displays are fabricated, a six-degree-of-freedom fixed cockpit simulator will be required [possible picture of X-15 simulator] for overall evaluation of the airplane handling qualities, response characteristics, and design compatibility of the control systems and augmentation systems. This complete simulator will be useful also for performance checks, mission analysis, developing piloting techniques, flight planning, defining emergency procedures, and pilot familiarization.

CONCLUDING REMARKS

The present state of the art of the piloted flight simulator leaves no major deterrent to the mechanization of required simulators for the design of present or future manned military airplanes. The fixed-base simulator with adequate presentation and controls is completely satisfactory for the investigation of a wide range of airplane problems. However, there are some areas which require some form of motion stimulus. Other areas remain where simulator requirements are not yet resolved, but work is continuing to better define these simulator requirements.

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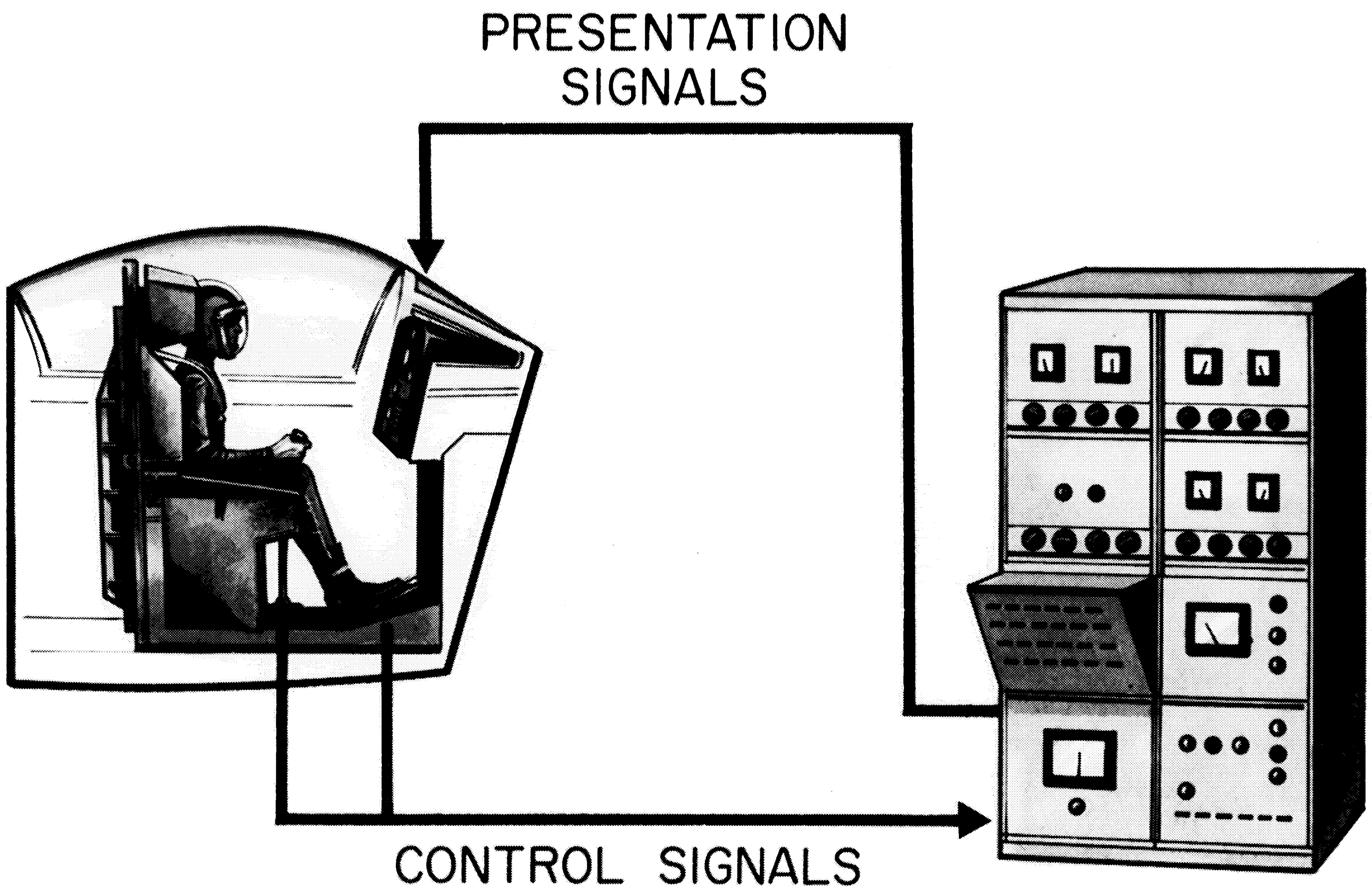
FIXED-BASE SIMULATOR



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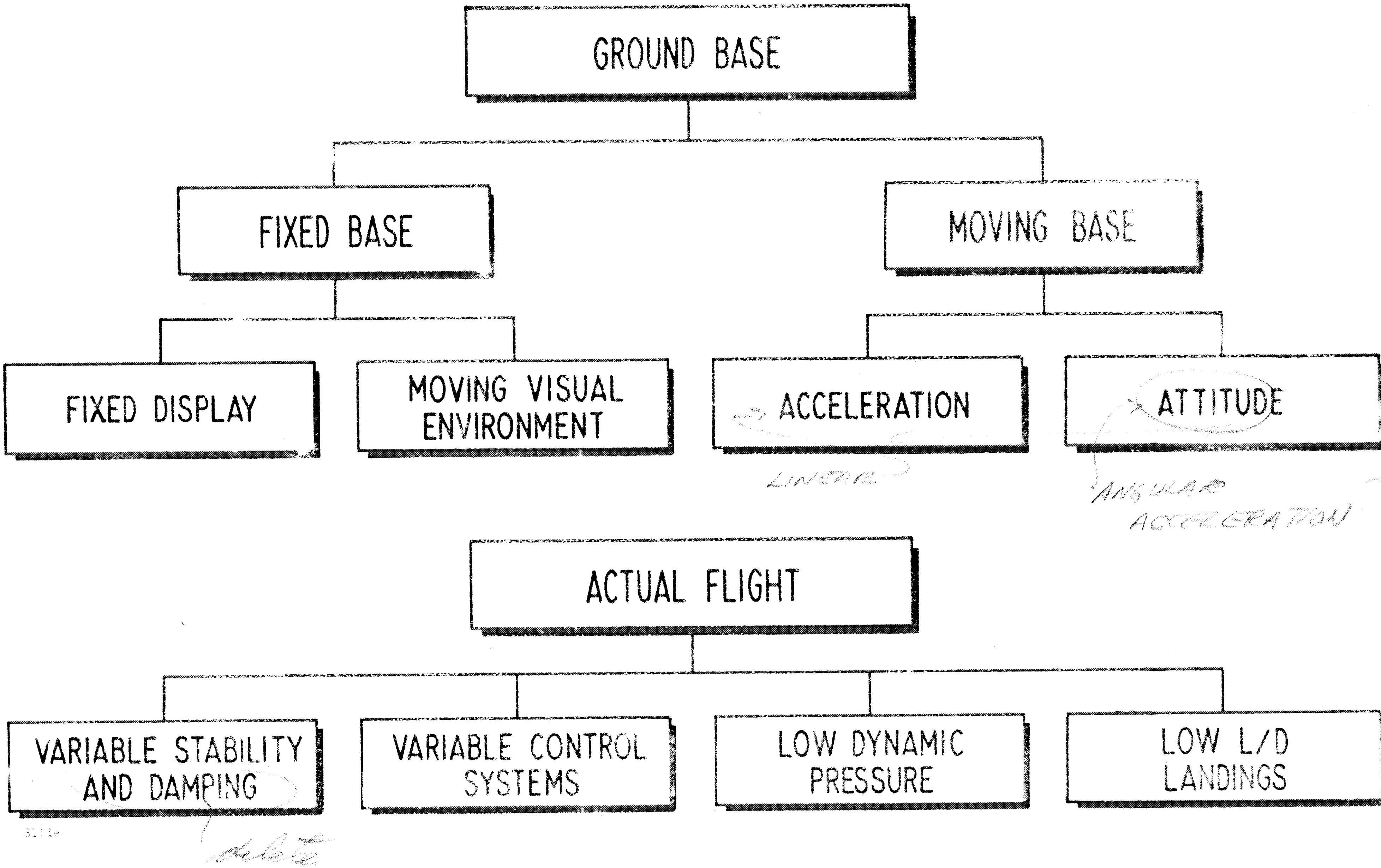
TYPES OF SIMULATORS



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SIMULATOR ~~PROBLEMS~~ STUDIES

AIRPLANE BASIC DESIGN

- BASIC STABILITY AND DAMPING
- ROLL CHARACTERISTICS
- PITCH UP CHARACTERISTICS
- CONTROL SYSTEMS
- DISPLAYS AND LANDINGS

MAJOR SYSTEM DESIGN

- AUGMENTATION SYSTEMS
- ADVANCED CONTROL SYSTEMS
- FIRE CONTROL SYSTEMS
- ENERGY MANAGEMENT
- THERMAL ENVIRONMENT

MISSION ANALSIS

- PERFORMANCE
- RANGING
- PILOTS CAPABILITY
- EMERGENCY PROCEDURES
- OPERATING TECHNIQUES

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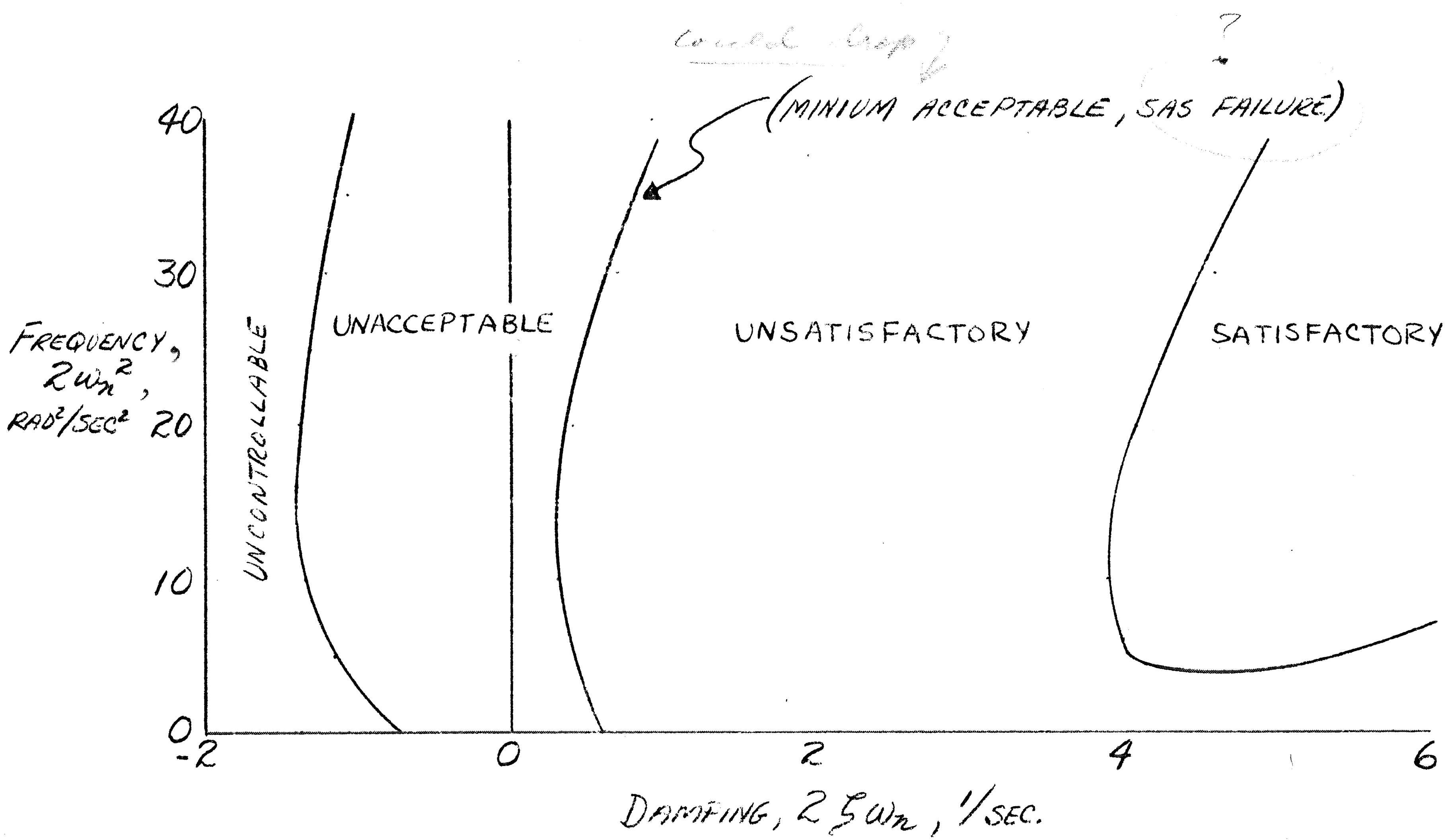
FLIGHT EVALUATION OF AIRPLANE LONGITUDINAL DYNAMICS



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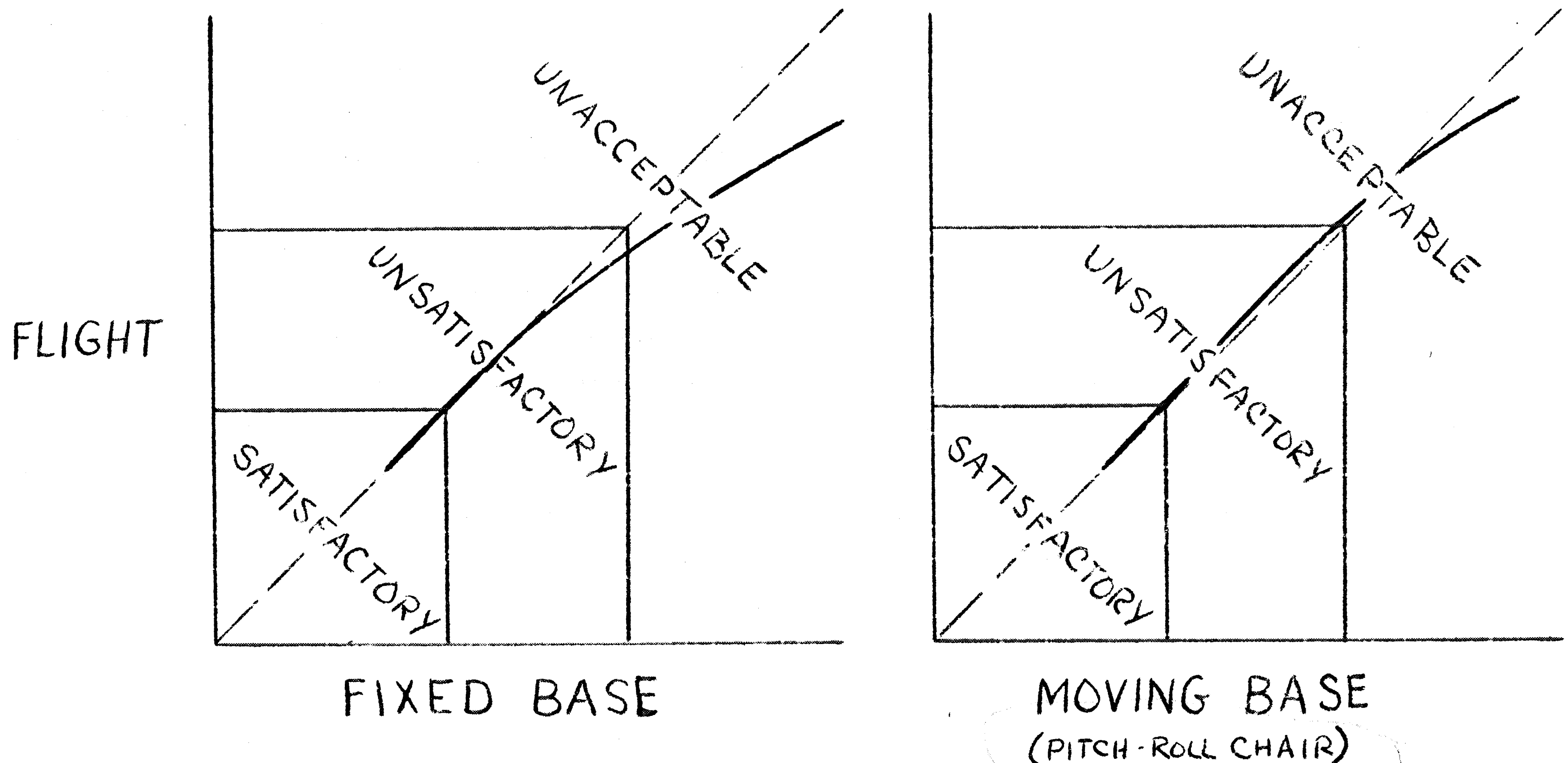
PILOT'S OPINIONS CORRELATION
(LONGITUDINAL DYNAMICS)

CORRELATION OF PILOT OPINION
OF
LONGITUDINAL DYNAMICS



will confuse since
this tests only longitudinal
mode. Note too
technique is

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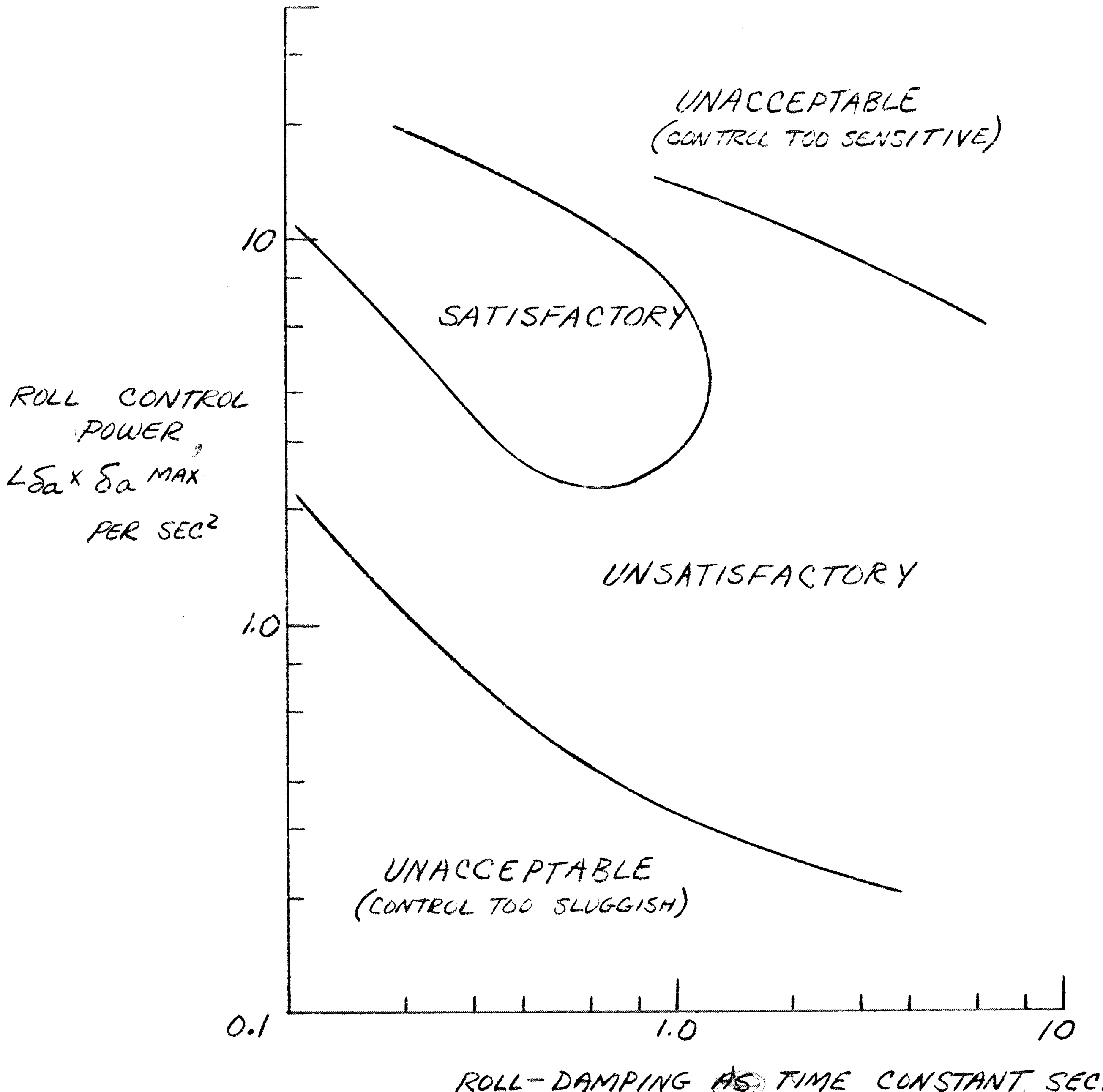
LATERAL CONTROL



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Slide 6

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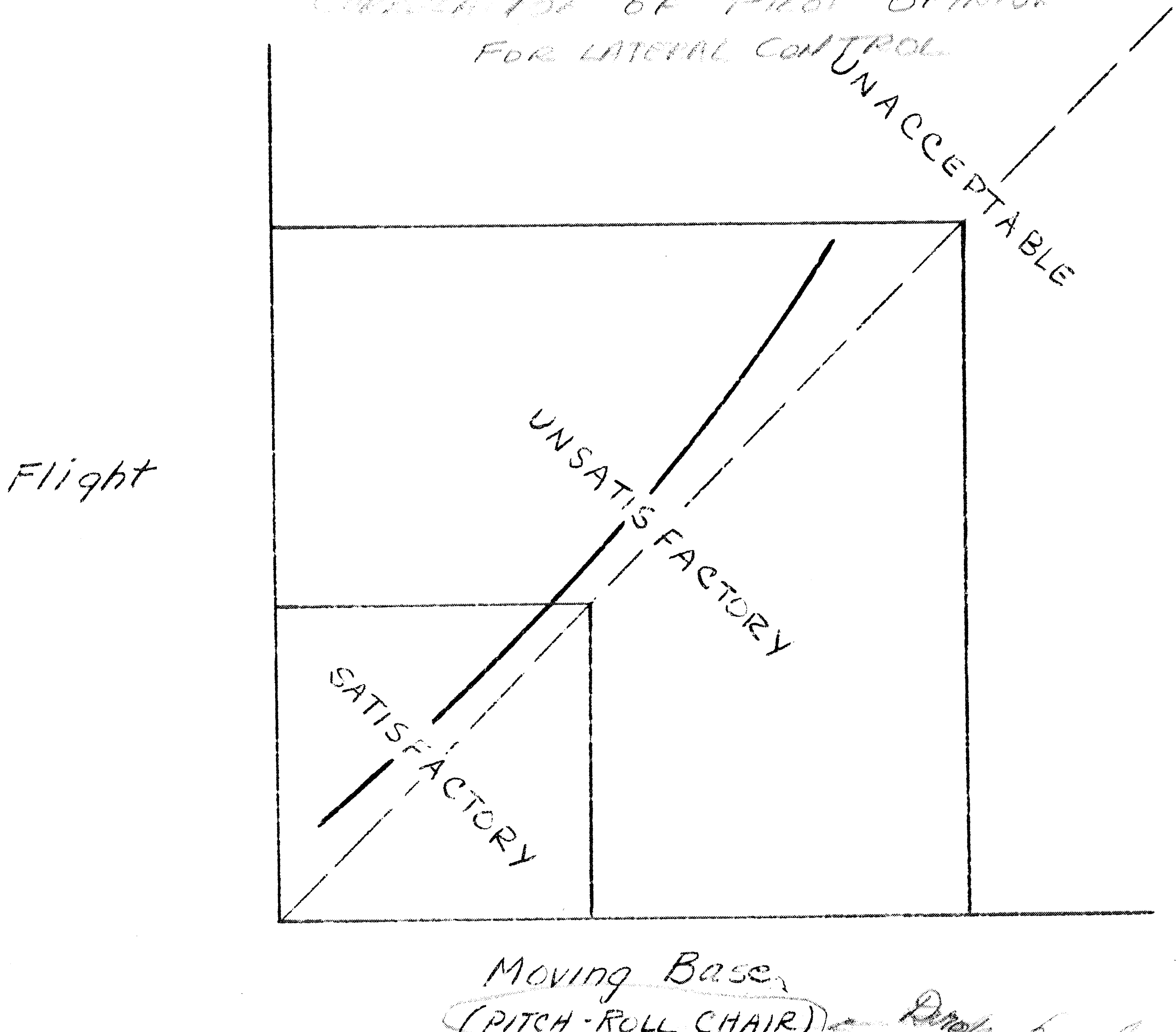
PILOT'S OPINIONS CORRELATION
(LATERAL CONTROL)

CORRELATION OF PILOT OPINION FOR LATERAL CONTROL



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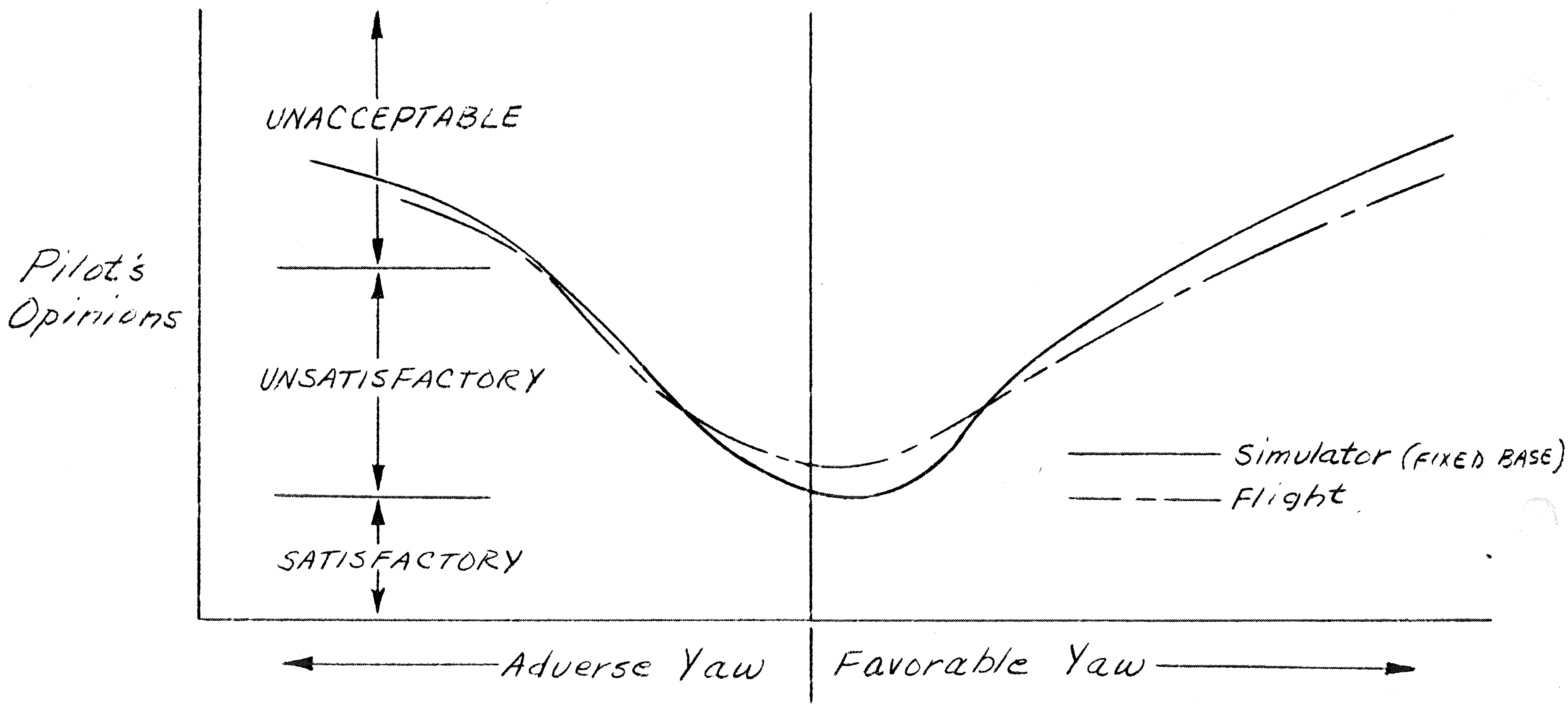
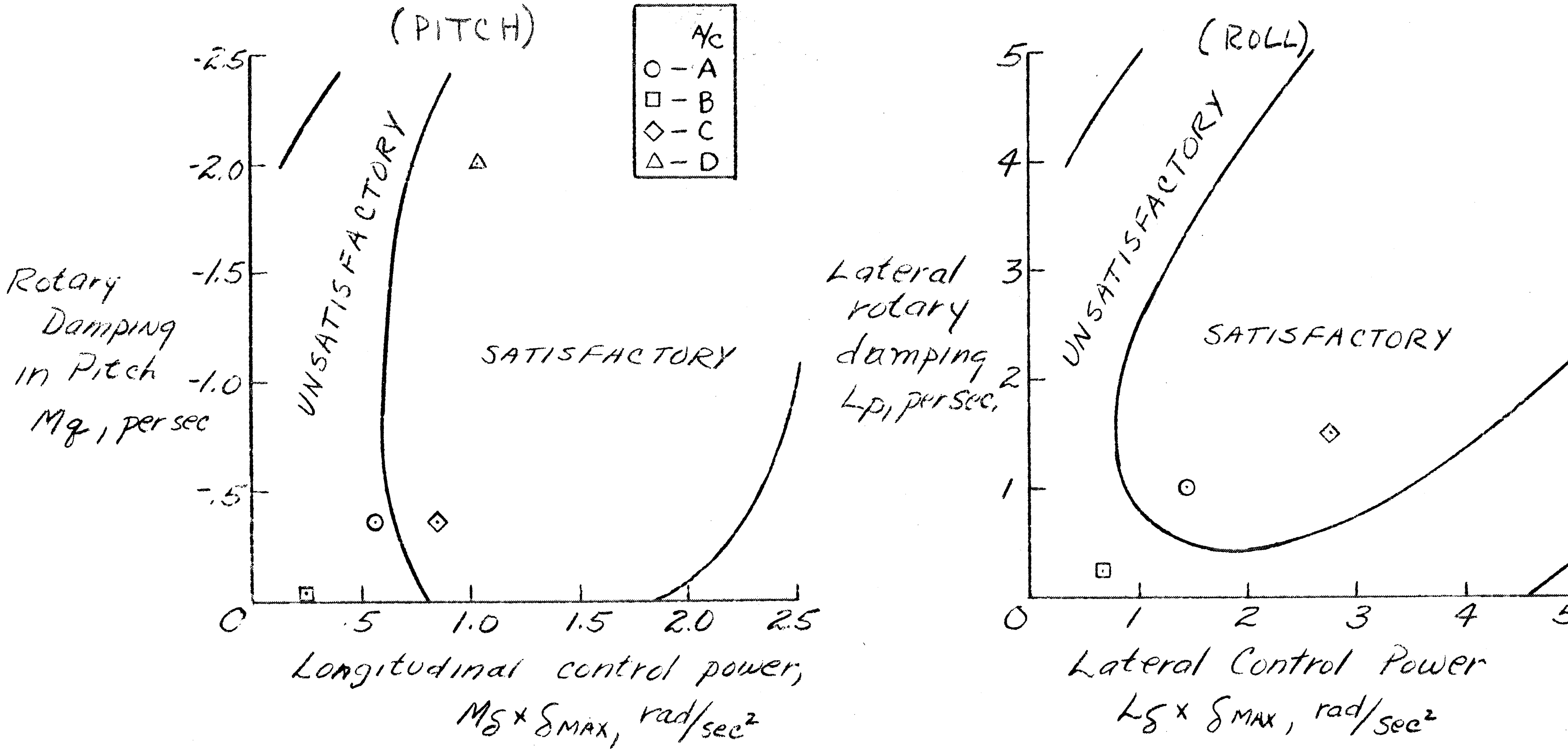
CORRELATION OF PILOTS OPINION

FOR CONTROL COUPLING



HOVERING CONTROL REQUIREMENTS



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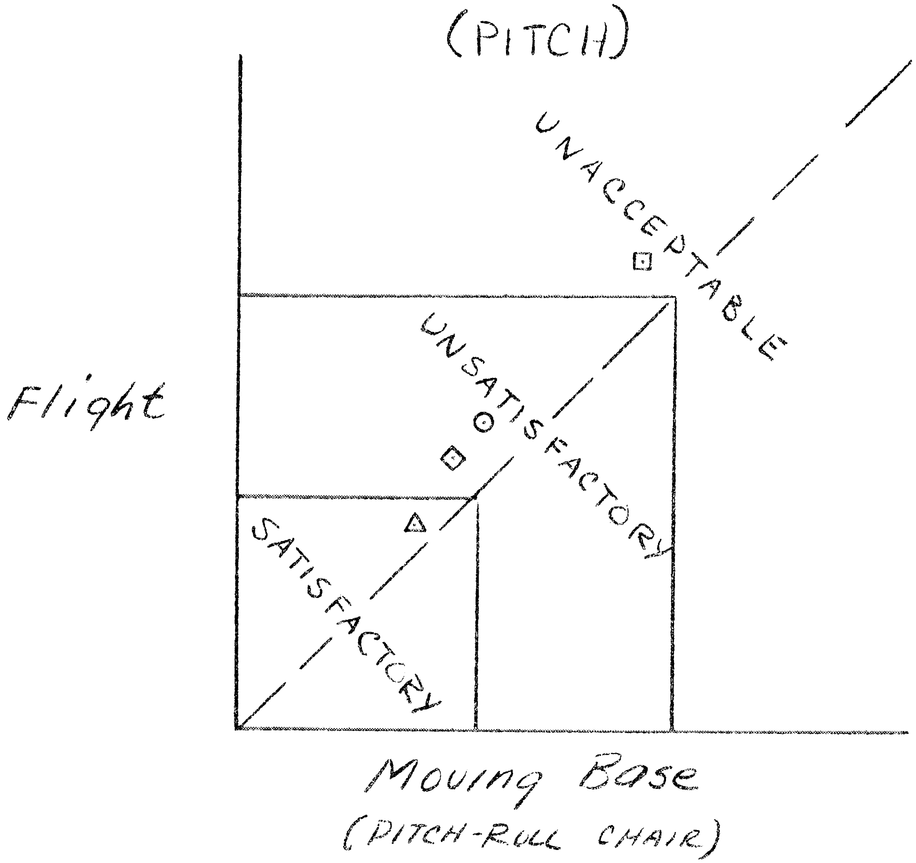
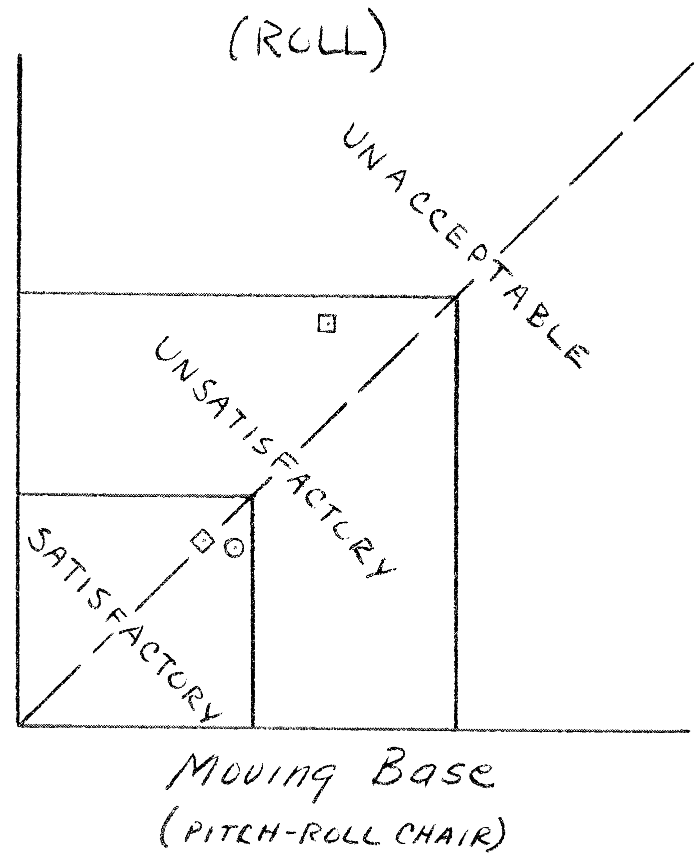
CORRELATION OF PILOT OPINION
FOR V/STOL CONTROL

PILOT'S OPINIONS CORRELATION
(V/STOL CONTROL)





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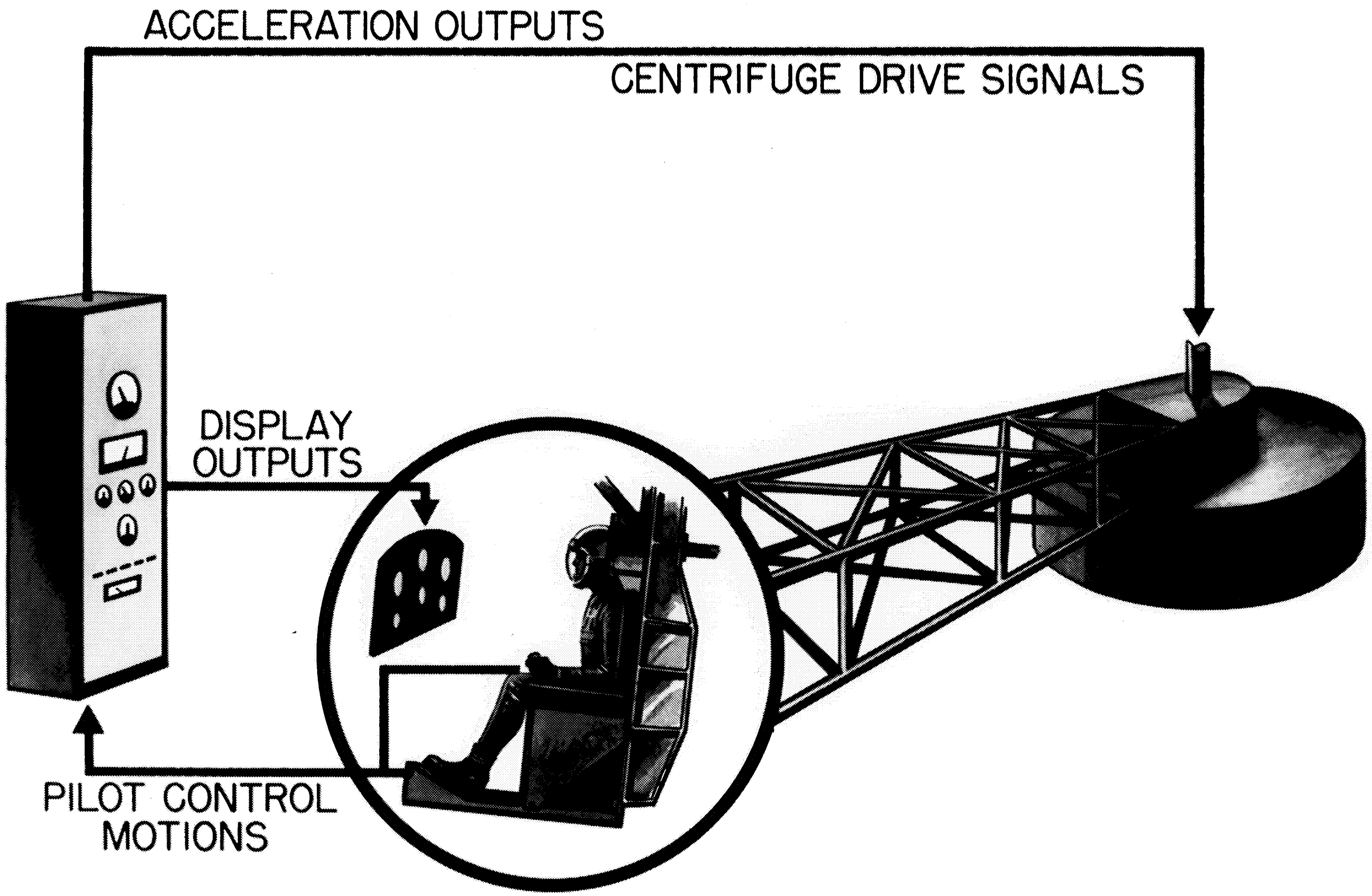
CENTRIFUGE DYNAMIC SIMULATION



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LOW LEVEL ATTACK AIRPLANE

SKETCH

DESIGN PROBLEMS

LONGITUDINAL CONTROL SENSITIVITY
ROLL CONTROL EFFECTIVENESS
RESPONSE TO TURBULENCE
CONTROL COUPLING
ROLL COUPLING
AUGMENTATION REQUIREMENT
AERODYNMIC COUPLING
SWEEP CHANGE EFFECTS

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